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FTD-ID(RS)T-0146-90

FOREIGN TECHNOLOGY DIVISION

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HUMAN TRANSLATION

FTD-ID(RS)T-0146-90 25 April 1990

MICROFICHE NR: FTD-90-C-000457

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English pages: 9

Source: Yingyong Shenyxue, Nr. 2, 1988, pp. 1-5

Country of origin: China
Translated by: Leo Kanner Associates
F33657-88-D-2188
Requester: FTD/TTTAC/Lt Michael S. Mills
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THE APPLICATION OF SAW DEVICES IN EXPANDED FREQUENCY SPECTRUM COMMUNICATIONS

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Received 22 April 1986

Expanded frequency spectrum communications, hereafter referred to as "expanded communications," is a very important technology in modern communications. If features good resistance to interference and good security capabilities. In the area of rangefinding, it is able to improve the rangefinding accuracy because rangefinding accuracy is related to the expanded band. In use, it offers code portion multiple addresses; multiple users can use a channel jointly.

SAW devices have many applications in a communications system [1]. This paper is intended chiefly to describe the application of the SAW-MSK signal modulator/generator [2] and the SAW convoluter [3-5] in an expanded communications system, and to report on several actual results.

In today's world, there are many forms of expanded communication. MSK (minimum frequency drift key control) signals are one kind of binary digit modulating signal whose excellent functions have attracted attention. This is because, in comparison with the frequently used PSK signals, they not only possess the features of a constant amplitude and continuous phase, but they also have a relatively concentrated energy spectrum. Radiated power outside the band rolls down quickly, and the crossover interference between the frequency channels is small. MSK offers a foundation for solving the difficulties of channel bands ever more crowded by the increasing development of modern communications.

*Feng Suochun has been transferred to the Chinese Academy of Sciences Guangzhou Electronics Technology Research Laboratory [note in original].

MSK signals can be realized very conveniently using SAW technology. Reference [2] reports on the results of the MSK signal modulator which we developed. An MSK modulator using SAW converts PSK signals to MSK signals; the phase of the MSK signals obtained is continuous. The frequency difference between different code elements is in accord with theoretical results. The spurious amplitude is ±7%. Performance is good, satisfying practical demands. We have also used an encoded bipolar δ-pulse array to drive the SAW-MSK modulator directly, and obtained MSK signals [2]; the spurious amplitude was ±11%. This is also able to satisfy practical requirements. However, the reason for selection of PSK→MSK signal conversion technology for application in real systems is not only that this method is able to obtain relatively good performance, but also that PSK signal modulation is rather simple, and easy to achieve.

PSK signal modulators are frequently used double balanced modulators. They are composed of two pulse transformers and several diodes, as Fig. 1 shows. It is best for this kind of modulator to use bipolar data code modulation; without using synchronous time gates, it is possible to obtain a quiet, forward protruding wave shape, and avoid carrier wave interference [2].

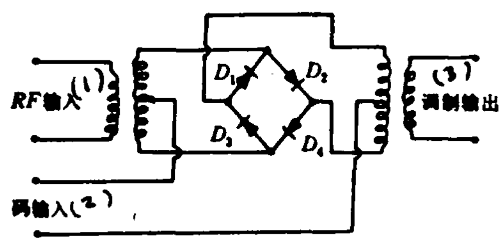

Fig. 1. Double balanced mixer.
Key: (1) RF input; (2) Coded input; (3) Modulated output.

Another SAW device in actual use in expanded communication systems is the SAW convoluter. The SAW convoluter, basically, has two structures. One is the SAW acoustoelectric convoluter [3], and the other is the SAW flexible convoluter [4, 5]. The SAW convoluter features a large band width and real-time (rapid speed) signal processing capabilities. It is able to perform convolution or correlation accurately using a relatively simple method; it is a self-adapting signal processor with a high degree of programmability. We have used all the kinds of SAW convoluters which we have developed to perform

convolution and correlation experiments on a variety of signal shapes [6]. These experiments show the flexibility of the SAW convoluter, and show that the performance of the SAW convoluters which we have developed is excellent. For performance data on our SAW convoluters, see Table 1.

Table 1. SAW convoluter performance specifications

Parameter	Model (Gap Style) Acoustoelectrical Convoluter	Flexible (MSC) Convoluter [4]
Central Frequency (MHz)	60	60
Input Bandwidth (MHz)	11	10
Mutual Effect Length (μs)	8	8,13
Convolution Effectiveness (dBm)	-50	-70
Dynamic Range Input	>70	>70
Dynamic Range Output	>70	>70
Resistance, Input (Ω)	40-50	40-50
Resistance, Output (Ω)	~50	~50

SAW convoluters are used in expanded frequency communications receiver systems. They are used for two purposes, matching correlation resolution and high-speed capturing and tracking (i.e. high-speed synchronization).

SAW convoluters, in their matching correlation resolution function, have the function of a programmable matching wave filter. When the code pattern changes, it is not necessary to change any component or the form of the remaining circuitry; all that is required for automatic adaptation is a reference signal that is the inverted image of the initially received signal. Figure 2 is the MSK signal's automatic correlation diagram that is obtained through the use of SAW convoluters. In it, the MSK signal's code pattern is a 32 bit M-series, $\{a_n\} = \{00000110111010100111110010110001\}$; the theoretical

Fig. 2. Automatic correlation of an MSK signal.

value for the main parasitic lobe ratio of the automatic correlation function is 12 dB, while the experimental value is 11.1 dB.

Another important application of SAW convoluters in expanded frequency communication receivers is the realization of rapid synchronization. In experimental systems, the time for synchronous searching must be very short. It is necessary to complete it in several hundred microseconds, and the signal used again is of protruding shape. For this reason, the conventional phase lock loop is difficult to implement. Using SAW technology, on the other hand, provides a simple solution. This is chiefly because SAW convoluter processing is at a real-time rate of speed. For example, under our specific conditions, the code signal is a protruding shape 32-bit MSK signal with a code element width of 0.2 μs, and a carrier wave about 60 MHz. Using a computer for digital processing, about 10^{11} operations are required, which will waste much time; using a SAW convoluter for direct processing in a middle frequency, on the other hand, only several microseconds are required to complete the job. For this reason, the capability of SAW convoluters to process signals rapidly provides a potent means for rapid synchronization.

Synchronous processing consists of three different stages: Coarse synchronization coincidence measurement, specific special collimation, and precision synchronized peak position measurement. The entire synchronizing circuitry is supplied by the SAW convoluter, delay circuitry, and coincidence gates. According to the signal pattern requirements for an actual system, a block diagram illustrating the principles of the coarse synchronization is shown in Fig. 3; it is implemented with four SAW convoluters searching in parallel. The protruding shape code sequences' length is 6.4 μs, so the length of the mutual effect area of the SAW convoluters is 12.8 μs (the length of two code sequences).

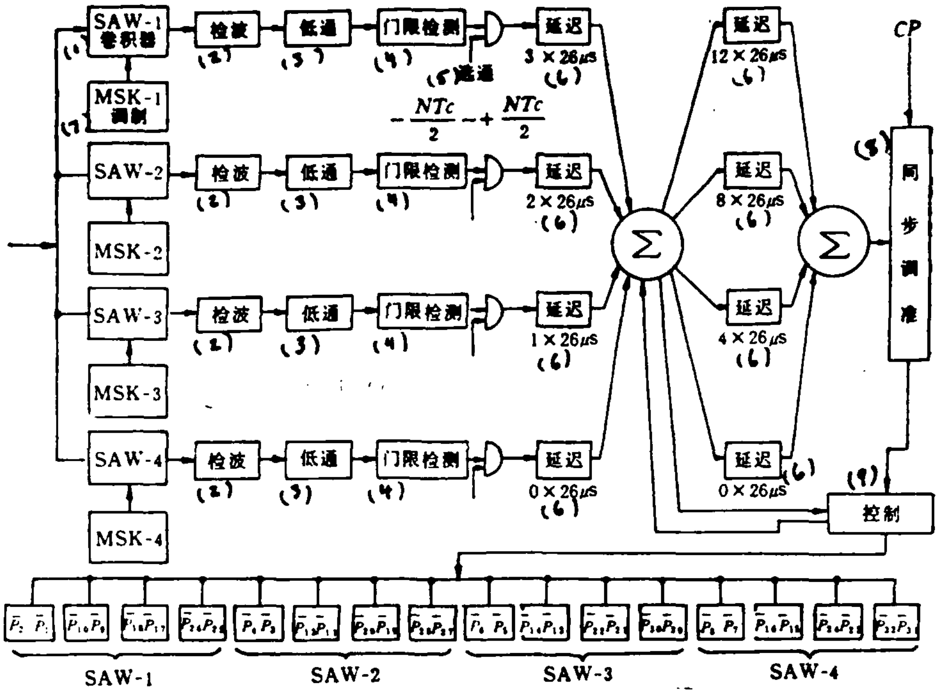

Fig. 3. Principle of coarse synchronization. Key: (1) Convoluter; (2) Rectification; (3) Low pass; (4) Switch limit testing; (5) Gate; (6) Delay; (7) Modulation; (8) Synchronization adjustment; (9) Control.

Based on the block diagram showing the principle of coarse synchronization (Fig. 3), the synchronized forward-position code (sometimes called the "masthead" code) and the information expanded frequency code require a total of 33 columns of different PN expanded frequency code. Of these, the M-sequence of 32 columns $(P_1, P_2, P_3, \ldots, P_{32})n=5$ is treated as the synchronized forward-position code; the other column is treated as an information expanded frequency code. In the process of coarse synchronization, the initial states of the four convoluters of the receiver are respectively added to the continuous cyclic local code sequence $\bar{P}_2$, $\bar{P}_1$; $\bar{P}_4$, $\bar{P}_3$; $\bar{P}_6$, $\bar{P}_5$; $\bar{P}_8$, $\bar{P}_7$ (where the line over the letter shows the conjugate code of the forward-position code time inverse) to implement searching. In this way, no matter what time the received signal's synchronized head arrives, the SAW convoluters will control the correlated peak output, as Fig. 4 shows. Figure 4(a) shows the state of the correlated peak when reaching synchronization time; Figure 4(b) shows the state of the correlation peak for

partial correlation before the synchronization time is reached. At this time, the main correlation peak is between $-NT_c/2$ — $+NT_c/2$ ($N=32$, $T_c=0.2$ μs). The gate switch is placed between $-NT_c/2$ — $+NT_c/2$ in order to capture the main correlation peak. In Fig. 4, τ is the time lag between the reference signal and the signal to be received, and Δt is the time lag between the non-synchronized time and the synchronized time main correlation peak position. $\tau = 2\Delta t$. Δt can be measured between the measured time and the corrected time. As for the adjustment reference signal's phase, it is possible to realize speedy synchronization. In order to guarantee its reliability, synchronous coincidence inspection is undertaken before adjustment, delaying the output of the SAW convoluters 1 through 4 respectively 3x26μs, 2x26μs, 1x26μs and 0x26μs. For the four coincident peaks, one coincident synchronization inspection is undertaken, and then the output changeover signal changes the four SAW convoluters' local code sequence respectively to $\bar{P}_{10}$, $\bar{P}_9$; $\bar{P}_{12}$. $\bar{P}_{11}$; $\bar{P}_{14}$, $\bar{P}_{13}$; $\bar{P}_{16}$, $\bar{P}_{15}$ to undertake cyclic searching. The above process is repeated, four times each. We now delay the 4 times' synchronous coincident inspection changeover signal respectively 12x26μs, 8x26μs, 4x26μs, and 0x26μs, and perform the second synchronous coincidence testing, again adding it to the synchronous adjustment circuit, and undertake time measurement and time checking. At this time, the coarse synchronization is declared complete. The precision of the coarse synchronization is as much as 1 chip of time.

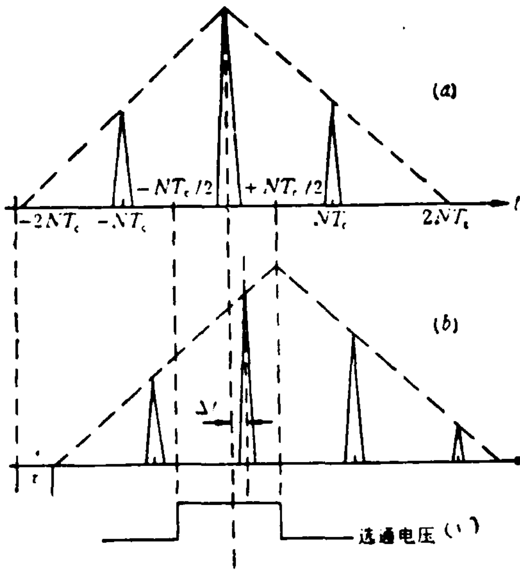

Fig. 4. (a) Correlated peak output during synchronization; (b) Correlated peak output before synchronization.
Key: (1) Gate voltage.

After coarse synchronization, the phase difference between the local reference signal's code sequence and that of the received signal is already

equivalent or less than 1 chip of time. To reduce the phase difference between them further, we use two SAW convoluters, using two $\pm T_c/2$ phase-shifting codes. Using the conducting forward/backward position rule, we bring the synchronization difference of the coarse synchronization to 1/8 chip of time. The principle of fine synchronization are shown in Fig. 5.

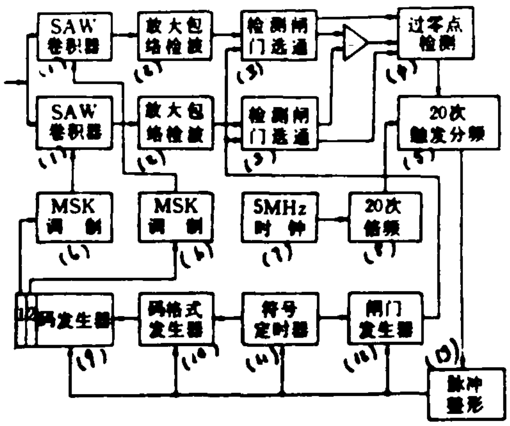

Fig. 5. Principle of fine synchronization. Key: (1) Convoluter; (2) Enlarged, packaged for rectification; (3) Inspection gate; (4) Past-zero point inspection; (5) Trigger scaling down, 20 times; (6) Modulation; (7) Clock; (8) Frequency multiplication, 20 times; (9) Code generator; (10) Code pattern generator; (11) Symbol timer; (12) Gate generator; (13) Pulse shaping.

When the signals entering the two SAW convoluters are staggered 1 chip of time, T_c, the output coincident signal peak of the two convoluters undergoes filtering and packaging for inspection and passes the gate; a wave shape such as shown in Fig. 6 is output. It passes through the subtractor, zero-point inspection is performed, and a narrow pulse is produced. It triggers 20 frequency dividers, producing a high-stability 5 MHz clock able to track automatically the false code phase of the received signal. When SNR=0dB, after fine synchronization, the difference between the clock phase and the received signal phase is equal to or less than 1/8 chip of time.

After the 5 MHz clock with a stability of $10^{-9}/12$ seconds has gone through 20 frequency multiplications, a pulse signal with a frequency of 100 MHz is produced. Its frequency stability is still the same as for the 5 MHz clock. Having undergone coarse synchronization, the code phase difference is within 1 chip; it can thus be seen from Fig. 7 that the area in which t_j

appears is $(-T_c/2, +T_c/2)$. Within this region, the position of t_j is decided by the code phase difference. If the phase of the machine's code and the receiving code phase are the same, t_j appears at T_1; but when the two codes' phases differ by 1 chip, t_j appears at time T_{10}. When the code phase difference is 0.48 chip, t_1 appears at T_4, as shown in Fig. 7.

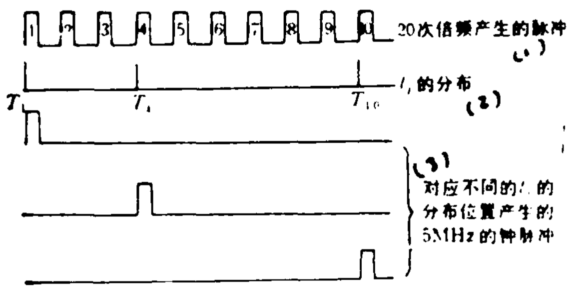

Fig. 7. Time wave shape generated by 20 triggered downscalings. Key: (1) Pulse produced by 20 frequency multiplications; (2) t_j distribution; (3) 5 MHz clock pulse produced corresponding to different distribution positions of t_j.

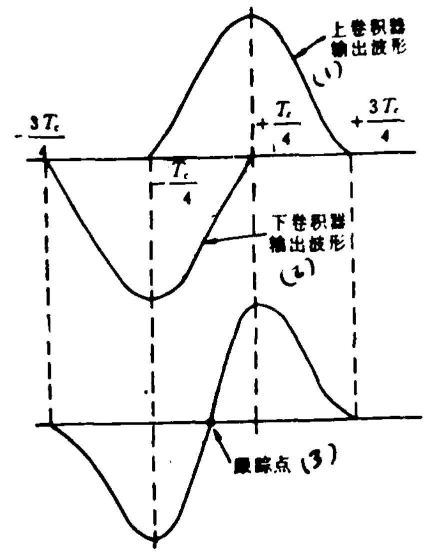

Fig. 6. Subtractor output wave shape. Key: (1) Upper convoluter output wave shape; (2) Lower convoluter output wave shape; (3) Tracking point.

Obviously, the phases of the 5 MHz clock generated by trigger frequency division at the times T_1, T_2, T_3, ..., T_{10} are each different. For this reason, the clock phases generated by trigger frequency division are able automatically to track the received signal's code phase, and fulfill the requirements of fine synchronization. An experimental system for fine synchronization is currently under development. Fig. 8 is a panorama of the hypothetical synchronization at the time of synchronization; it is in agreement with the theoretical results shown in Fig. 4(a).

The coherent peak of the received signal measured directly by the SAW convoluter on the mid-frequency and the reference signal, on the basis of different positions of the coherent peaks, can measure the accurate data signal. Based on different information shown on the corresponding position of

the main coherent peak on the code sequence axis, it is possible accurately to recover the corresponding information, and then to compare to the special key the obtained information, recovering the information in the original signal s(t).

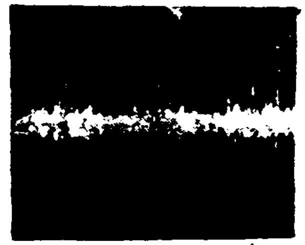

Fig. 8. Synchronization panorama.

In order to test the influence of the Doppler effect on the SAW convoluter, we also undertook analog testing. Fixing the reference output signal of the SAW convoluter as 57.50 MHz, we changed the carrier frequency of the received signal. The results of the experiment are as shown in Fig. 9. These results show that the Doppler effect has no great influence.

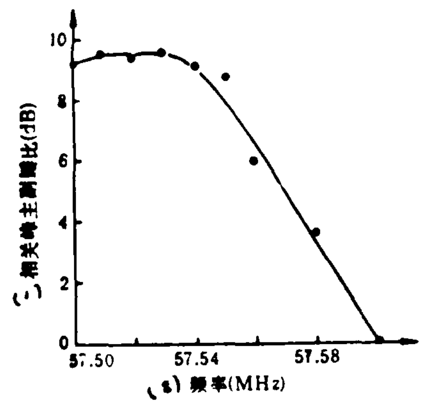

Fig. 9. Influence of the Doppler effect. Key: (1) Coherent peak main parasitic lobe ratio; (2) Frequency.

The experiments in this paper related to expanded frequency systems were carried out with the cooperation of the Nanjing Aviation Academy. At this point we wish to express our gratitude to the other colleagues who participated. This paper was read carefully and corrected by Professor Ying Zongfu, to whom the author at this point wishes to express his special thanks.

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